BONDING PROCESS AND MECHANISM OF ALUMINUM ALLOY BONDING SHEET①

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ABSTRACT The hot rolling bonding process of 3-layer bonding sheet of Al-Si/Al-Mn Al-alloy has been studied. In order to obtain the isostrength bonding, the hot rolling bonding technology (hot rolling temperature, hot rolling reduction, initial cladding rate) was optimized by using an orthogonal method and a variance analyzing method. The result shows that when the optimized hot rolling temperature is 490 ℃, the optimized hot rolling reduction is 90%, and the optimized initial cladding rate is 13%, the shear strength of bonding surface attains 99.51 MPa. The effect of bonding technological factor on bonding strength and the appearance of the over-burden face were analyzed and determined with the aid of metallographic microscope, scanning electron microscope and spectrometer. It was pointed out that the hot rolling bonding reduction is the main factor affecting bonding strength and the next one is hot rolling temperature, but the effect of initial cladding rate is very small. Besides, diffusion bonding mechanism was believed playing a main role in bonding mechanism.

Key words aluminum alloy bonding sheet rolling bonding bonding mechanism

1 INTRODUCTION

The three layer aluminum alloy bonding sheet (Al-Si/Al-Mn/Al-Si) as one of the key materials for aluminum heat exchangers has a wide application because of its advantages of light weight, good braze welding ability, reliable properties and corrosion resistance etc. At present, the widest used way making multilayer aluminum alloy bonding sheets is hot rolling. This paper aims to study the hot rolling bonding process of three layer Aluminum alloy bonding sheets, and to optimize the key process parameters and approach a bonding mechanism.

2 MATERIALS AND TEST METHOD

In this test, 4004 alloy was used as a cladding material and 3003 alloy as a matrix material (core material). The chemical composition of the two materials is shown in Table 1. After being heated and rolled, the metallographic, scanning, spectral and physical property samples were prepared respectively according to the required sizes and inspected one by one.

The several important parameters of hot rolling bonding process of aluminum alloy bonding sheet are rolling temperature, hot rolling reduction and initial cladding rate. In order to exactly study the influence of the above three factors during hot rolling bonding on the bonding strength and to reduce the test work possibly, the test was done through an orthogonal design $L16(4^5)$ (see Table 2).

Table 1 Chemical composition of the test alloys (%)

Alloy	Cu	Mg	Mn	Fe	Si	Zn	Ti	Al
3003	0.06	–	1.15	0.38	0.12	0.01	0.01	balance
4004	0.01	1.7	0.03	0.22	9.88	0.02	0.01	balance

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Table 2 Factorial-level table of orthogonal test

Level	Hot rolling temperature/ ℃	Hot rolling bonding reduction/ %	Initial cladding rate/ %
1	410	50	11
2	430	60	13
3	450	70	15
4	490	90	17

3 TEST RESULT AND ANALYSIS

3.1 Determination of the optimized process system

A test of bonding strength has been done according to the test plan in Table 2, whose result was analyzed by polar difference analysis (see Table 3). Combining the effects of hot rolling temperature, hot rolling bonding reduction and initial cladding rate on the bonding strength of alloys (see Fig. 1) and variance analysis, the better level of each factor was selected so as to determine an optimized hot rolling process system.

From Table 3, it can be seen that the rolling bonding reduction is the main factor affecting the bonding strength of alloys and the next factor is the hot rolling temperature, the initial cladding rate can be neglected because its effect is very small.

As seen from Fig. 1, the bonding strength increases monotonically with increasing of the hot rolling temperature and hot rolling bonding reduction within the design range, and is hardly affected by the initial cladding rate. When the hot rolling temperature reaches 490 ℃, the bonding strength becomes the highest (i. e. 94.47 MPa); when the bonding reduction is 50%, the bonding strength is lower (i. e. 88.13 MPa); when the hot rolling bonding reduction increases from 50% to 70%, the bonding strength increases to 93.83 MPa; and when the bonding reduction increases from 70% to 90%, the bonding strength only has an increase of 1.83 MPa. Thus it can be known that the bonding strength increases rather quickly when the hot rolling bonding reduction is between 50% and 70% and its increase rate becomes slow when the hot rolling bonding reduction exceeds 70%.

Table 3 Polar difference analysis of the influence of various factors on the bonding strength

Factors	Polar difference
	Bonding strength/ MPa
Hot rolling temperature	20.92
Hot rolling bonding reduction	30.12
Initial cladding rate	1.6

From what analyzed above, it can be seen that under the test condition the selected optimized process is as follows: hot rolling temperature: (490 ± 5) ℃; hot rolling bonding reduction: 90%; initial cladding rate: 13% or so.

3.2 Verification of an optimized test plan

With the optimized process obtained

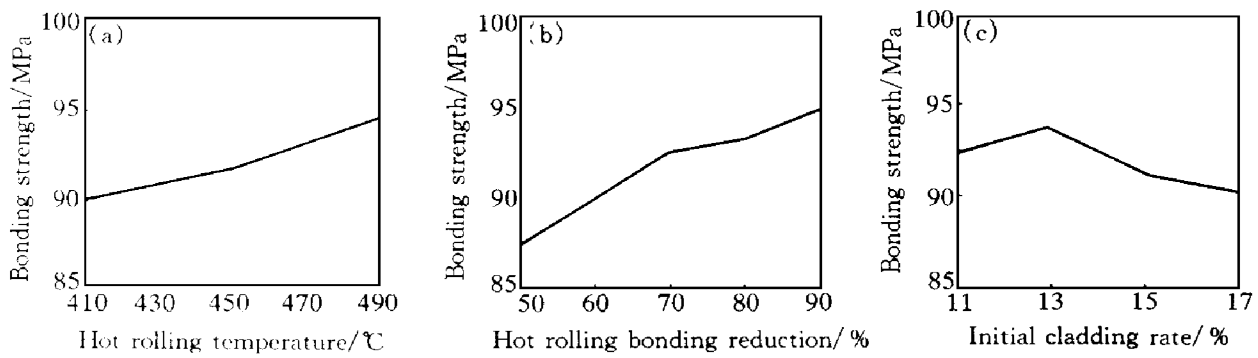

Fig. 1 The influences of hot rolling temperature (a), hot rolling bonding reduction (b), and initial cladding rate (c) on alloy bonding strength

through an orthogonal test, 3003 alloy ingot having a thickness of 283 mm and 4004 alloy cladding sheet having a thickness of 50mm are bonded through the hot rolling.

After hot roughing, the reduction has reached 95. 4%, the bonding strength at the bonding interface is 99. 5 MPa and the shearing strength of 3003 alloy (Matrix) is 105 MPa, which basically attains the isostrength bonding. From Fig. 2 and Fig. 3, it can be seen that the bonding of matrix and cladding material is considerably good, which proves that the above optimized hot rolling bonding process has a rather good guiding role to practical production.

Fig. 2 Bonding interface after hot roughing (200×)

Fig. 3 Bonding interface after hot finishing (200×)

4 ANALYSIS OF BONDING MECHANISM

When the bonding sheet is rolled, owing to the change of various process parameters, the complicated interface reaction is caused, as a result, the changes of the interface microscopic appearance and composition take place, and affect the bonding strength in different degrees.

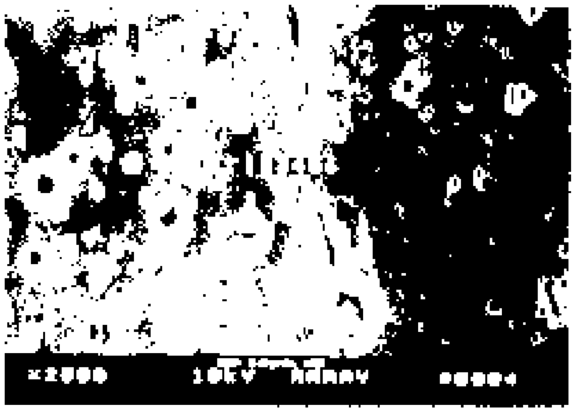

Fig. 4 The interface appearance of a bonding sheet in early hot rolling period (hot rolling temperature 490 ℃)

Before the two alloys are bonded, the cleaned surface is soon covered by oxide film and adsorption film in common atmosphere. Only by getting rid of these covers from the contact surfaces, can the practical physical contact be formed[1, 2]. In the early hot rolling bonding period, the covers and oxide film on the surfaces of matrix material 3003 alloy and cladding material 4004 alloy are cracked under the effect of the rolling pressure[3, 4], as a result, the matrix metal is exposed. As can be seen from Fig. 4, when a reduction reaches 19. 5%, the crackes attain a certain width and under the effect of the rolling pressure, the fresh metal of both sides of the interface is extruded from the crackes and contacts each other to form a bonding interface. At the moment, because the rolling time is comparatively short, the matrix material and cladding material are just beginning to bonding, although the hot rolling temperature is 490 ℃ and it is within the range of diffusion temperature put forward by Kazakov[5], the main element of Mn of the matrix material and the main element Si of the cladding material have not diffuse toward the other side (see Table 4). In accordance with the effect theory put forward by Korkendal[6], the diffusion depth value varies as the square root of diffusion time, so in the early hot rolling period, the diffusing phenomenon is very faint so that the bonding strength of the alloys is extremely low. Such lower bonding force is not able to produce firm joint between the surface atoms. In order to reach the metallurgical bond at metallic interface, the atoms and ions at the contact points of metallic interface must have the lowest energy level. When atoms or ions reach this energy level, the direction of atomic bonds will be weaken so that the metallic bond will form between the atoms of the two surfaces and the contacted surfaces of the two metals begin to form welding on[7].

Table 4 Element contents of spectrum in Fig. 4(%)

Element name	Sample number					
	1	2	3	4	5	6
Si	4.24	3.28	4.54	3.77	–	–
Mn	–	–	–	–	2.36	2.69

Along with the progress of the rolling process and continuous increase of the deformation degree, the inter-diaper amounts of the two alloys increase and form more binding sites. Because the temperature is high during the hot rolling, as time prolongs further the element diffusion at the sides of an interface is continuously sharpening and has a certain diffusing depth so that point binding has changed into face binding. After hot roughing is completed, the matrix material and cladding material form a good bonding interface (see Fig. 2). Under the circumstances of the other process parameters unchanged and within the same rolling time, the higher the rolling temperature is, the faster the diffusing speed and the more evident the diffusion phenomenon will be. After hot roughing at 410 ℃ and 490 ℃, the total reduction of alloys resches 95% or so and the gaps at the interface of a bonding sheet can't be seen completely, only by the different structures of the two sides can the interface be distinguished (see Fig. 5 and 6). When the hot rolling is carried out at 410 ℃, the diffusions of the elements at the two sides of an bonding interface take place (see Fig. 5). Because the temperature and diffusion degree of elements are low and the intense degree of interfaces binding is not high so that the bonding strength is comparatively small (see Fig. 1). When rolling is carried out at 490 ℃, the degrees of Si and Mn diffusing each other at the interface increase because the temperature is high (see Table 6), the diffusing phenomenon is more evident than that at 410 ℃, the corresponding metallurgical bond on the interfaces is better, so that the bonding strength at the interface further increases. From Fig. 7 it can be seen that after hot rolling at 490 ℃, the metal plastic deformation band at the crack of shearing sample interface is comparatively evident and there is no trace of mechanical bonding of two different alloys, which proves that a metallurgical bond on the bonding surface constitutes the majority and the interface bonding strength of alloys is as high as 99.5MPa, thus the rolling bonding sheet

Fig. 5 The interface appearance after hot roughing at 410 ℃

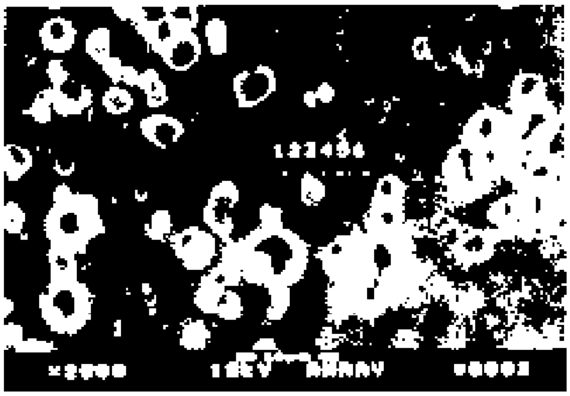

Fig. 6 The interface appearance after hot roughing at 490 ℃

Table 5 Element content of spectrum in Fig. 5

Element name	Sample number								
	1	2	3	4	5	a	6	7	8
Si	3. 67	3. 67	3. 77	4. 34	4. 52	2. 21	1. 3	–	–
Mn	–	–	–	–	–	2. 2	3. 98	3. 98	3. 92

Table 6 Element content of spectrum in Fig. 6

Element name	Sample number						
	1	2	3	4	5	<	6
Si	6. 32	5. 92	5. 76	3. 28	2. 10	1. 25	–
Mn	–	–	2. 32	3. 64	3. 30	3. 70	4. 67

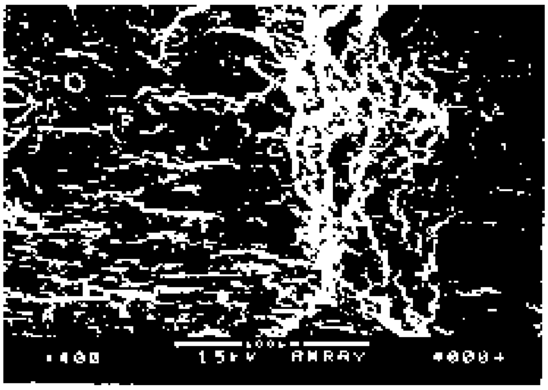

Fig. 7 The apperance of a crack at an interface(of the matrix of 3003 alloy) of a shearing sample

reaches the isostrength bonding. This shows that diffusion bonding mechanism plays a main and important role in the hot rolling bonding of bonding sheets.

5 CONCLUSIONS

(1) The hot rolling bonding process parameters of three layers of 4004 and 3003 alloy bonding sheets have a very important effect on the bonding strength of bonding interface. A rolling bonding reduction and a rolling temperature are the main factors affecting the bonding strength and the effect of initial cladding rate is very small.

(2) 4004 and 3003 alloy bonding sheets basically attain isostrength bonding because an optimized hot rolling bonding process is adopted, of which the rolling temperature is (490 ±5) ℃, a bonding reduction is above 90% and the initial cladding rate is 13% or so.

(3) When three layers of 4004 and 3003 alloy are bonding, in the early hot rolling period and under the effect of high rolling force, the oxide film and adsorption film on the surface are cracked, that the surfaces of two alloys are exposed and contact each other. As the deformation amount increases, when the atomic energy on the interface contact zone of two alloys reaches the lowest level of metallurgical bond, metallic bonds between the atoms on the surface begin to form, so that welding on is begin. Along with the progress of hot rolling, through the diffusion of Si and Mn at contact interface, the firm metallic welding is done.

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